August 17, 2004

David E. Hilliard
202.719.7058
dhilliard@wrf.com

VIA ELECTRONIC FILING

Marlene Dortch, Esq.
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: *Ex Parte* Presentation - WT Docket No. 03-103

Dear Ms. Dortch:

On behalf of Verizon Airfone Inc., I am transmitting a paper by Dr. Jay Padgett of
Telcordia responding to certain technical presentations by AirCell and a paper by
Dr. Anthony Triolo of Telcordia responding to presentations by Boeing.

These technical papers demonstrate that the latest analyses by AirCell and Boeing
concerning their competing proposals for accommodating multiple broadband
service providers in the Air-to-Ground (ATG) service are flawed and neither refute
the technical analysis previously provided by Verizon Airfone/Telcordia, nor solve
the debilitating interference problems that Airfone/Telcordia have shown would
result from the AirCell and Boeing proposals.

Background. As the Commission is aware, ATG uses spectrum in the 849-851
MHz and 894-896 MHz bands. The aircraft receives on the low band and transmits
on the high band. The current band plan only supports narrowband transmissions
(primarily speech), using 6 kHz channels. Although four licenses were originally
authorized, Verizon Airfone is the only remaining service provider using the ATG
bands. Airfone has proposed a modification of the Commission's technical rules to
permit it to provide broadband service. Under Airfone's proposal, the rules would
permit a single 1.25 MHz wideband channel in each direction in order to support
data-centric applications such as e-mail and web browsing that passengers are
demanding. The 1.25 MHz bandwidth specification will allow the use of broadband
technologies developed for terrestrial mobile radio services.

AirCell originally proposed that the ATG bands could be shared by two providers
by reversing the duplexing for the second provider (that is, having the second
provider's aircraft receive on the high band and transmit on the low band). Verizon
Airfone/Telcordia submitted a technical analysis demonstrating that such a scheme
would result in severe interference between the two providers' systems. AirCell's

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submission has attempted to refute technical analyses provided by Verizon Airfone/Telcordia. In addition, AirCell has amended its original sharing proposal to suggest that the 4 MHz of ATG spectrum can be shared by as many as *four* service providers. AirCell claims that the use of polarization isolation among providers, in addition to reversing the duplexing for the second provider, will enable this further sharing of the ATG band.

Boeing originally suggested the use of adaptive antennas on all aircraft and base stations, which it claims will alleviate the interference problems associated with multiple, broadband use of ATG spectrum by creating highly directional beams. Verizon Airfone/Telcordia's technical analysis demonstrated that this proposal was not commercially feasible. Boeing has asserted that Verizon Airfone's analysis of its proposal is flawed.

Analysis of the latest AirCell Filings and Proposals. AirCell attempted to respond to Verizon Airfone/Telcordia's technical analyses. As the attached technical paper makes clear, however, nothing in AirCell's rebuttal filings disproves Airfone/Telcordia's analysis. For example:

- Although AirCell claims that the 10 dB system implementation margin used in Telcordia's analysis is unnecessary, AirCell's own measurement data confirm the reasonableness of the margin assumed by Telcordia;

- AirCell's original proposal ignored base-to-base station interference. AirCell now attempts to provide a rationale for doing so, but its explanation is unrealistic in that it assumes antenna performance that would never be achieved;

- Telcordia demonstrated that AirCell's reverse duplexed system would suffer debilitating interference from the Naval air search radar in the 902-928 MHz band. AirCell's submission attempts to rebut that showing, but it neglects to account for the curvature of the Earth in its calculations, and therefore the analysis is fatally flawed; and

- AirCell's proposal would require very low power mobiles on aircraft that would support low rate speech circuits only, precluding the provision of broadband data service desired by passengers and frustrating technological evolution.

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In short, nothing in the latest AirCell filings refutes the Verizon Airfone/Telcordia analyses that a reverse duplex system in the ATG band would not be viable.

Additionally, AirCell has modified its previous proposal of allowing two ATG service providers, operating in a reverse duplex configuration, to add two more service providers utilizing cross polarization isolation. The attached technical response clearly shows the new AirCell scheme is fundamentally flawed as well because:

- Any isolation gained by cross polarization will be significantly overwhelmed by other variables;

- AirCell's analysis does not even attempt to model more than two service providers; it provides no support for sharing by four providers; and

- While AirCell justifies its claimed polarization isolation by reference to a 1997 measurement report, detailed examination of that report reveals no data or conclusions about polarization isolation.

Accordingly, the use of polarization isolation in the ATG band still will not resolve the significant interference effects and would prohibit the provision of a broadband service.

Boeing Proposal . Boeing claims that Verizon Airfone/Telcordia failed to consider its latest proposal. That is simply wrong. Contrary to Boeing's assertions, the previous analysis filed by Verizon Airfone considered Boeing's amendments to its initial proposal and showed that it still was not commercially feasible. The attached technical paper provides further analysis of Boeing's proposal, based on the clarification offered by Boeing that its proposal required the placement of base stations on a regular grid. In short, the Boeing proposal is still problematic because:

- Boeing's proposal would constrain all carriers to a rigid grid-based ground station deployment which is unrealistic in actuality;

- Boeing's proposal would largely prevent operation below 10,000 feet thereby generally precluding the service required for government, general aviation, and airline administrative use; and

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- Boeing has stated that its proposal would provide average data rates of 12 kb/s to passengers. These are less than can now be achieved. This would not support the kinds of broadband services passengers are demanding.

In short, the technical analyses and responses provided in the attached papers demonstrate clearly that the 800 MHz air-to-ground allocation provides sufficient spectrum for only one broadband system. The proposals made by AirCell and Boeing have significant technical and commercial flaws that make them unsuitable for deployment and preclude the provision of usable broadband services to the American public.

Please contact me with any questions concerning this matter.

Respectfully,

/s/ David E. Hilliard

David E. Hilliard
Counsel for Verizon Airfone, Inc.

Attachments
cc: Shellie Blakeney, Roger Noel, David Furth, Katherine Harris, Jay Jackson,
       Julius Knapp, Ira Keltz

Response to Recent AirCell Filings and Summary Comments on AirCell Proposals

WT Docket 03-103

Dr. Jay E. Padgett
Telcordia Technologies, Inc.
Applied Research
Wireless Systems and Networks

August 16, 2004

This response addresses two recent papers filed by AirCell in WT Docket 03-103. The first [3] consists of comments on a paper written by Telcordia [2] and filed by Verizon Airfone. The second [4] is a follow up ("Part 2") to AirCell's initial analysis [1].

First, summaries are provided of the responses to [3] and [4], and then detailed explanations are given. Following that, a summary of major comments on AirCell's overall proposals and analyses is provided.

Summary of Response to [3]

1. Telcordia allowed a 10 dB system implementation margin, based on Airfone's operational experience, to account for non-idealities, whereas AirCell based its analysis on perfect free space propagation with only a 3-dB cable loss. AirCell claims that such a margin is unnecessary; however, recent measurement data on the air-to-air path published by AirCell in [4] show a variation of approximately 10 dB (over free-space loss), and it is reasonable to expect that even greater variations would apply to the air-to-ground link due to the potential for strong ground reflections. Telcordia therefore continues to believe that 10 dB is a reasonable implementation margin to account for non-idealities in propagation and equipment.

2. Whereas in [1] AirCell ignored base-to-base interference for cross-duplexed systems, Telcordia showed that in AirCell's "airport scenario" the base stations of oppositely-duplexed systems would be within each other's radio horizon. In [3], AirCell disputes Telcordia's claim that base-to-base interference would be problematic; however, new calculations are provided by AirCell in [4], intended to show how base-to-base interference can be mitigated with antenna patterns. In fact, in addition to implicitly acknowledging the problem, these calculations show that such mitigation is not practical in actual implementation, because the required antenna elevation discrimination is too large (about 25 dB rolloff in 1 degree of elevation change). Such a specification is unrealistic from the perspectives of antenna design, installation, and operation (antenna sway can exceed 1 degree). Further, even the

specification provided by AirCell would not eliminate the base-to-base interference, but rather is intended to reduce it to a level 3 dB below the noise floor. The interference from two interfering base stations therefore would be equal to the noise floor and would significantly reduce the reverse link capacity. For a 6-dB allowed noise rise, the capacity reduction would be 33%. Although the transmit power levels of all aircraft could be raised to partially compensate, this would increase the aircraft-to-aircraft interference problem for cross-duplexed systems.

3. Telcordia explained that the system with duplex inversion (aircraft receive band at 894-896 MHz) would be much more subject to interference from the AN/SPS-49 Naval air search radar than a system with normal duplexing. The AirCell comments in [3] disagree based on calculations that do not account for the radio horizon (due to curvature of the Earth), despite the fact that the radio horizon was clearly explained in [2]. AirCell's calculations and its assertions based on those calculations are therefore not valid.

4. Telcordia explained that the operating mode and maximum total reverse link transmit power per aircraft assumed by AirCell (23 dBm) do not account for technological evolution and reverse link applications other than the low-rate speech circuits assumed by AirCell. In [3], AirCell continued to insist that air to ground (ATG) traffic will be predominantly low-rate voice. However, adopting FCC Rules allowing cross-duplex operation based on such a short-term view of ATG applications will tend to become a self-fulfilling prediction, limiting technology growth.

5. Telcordia noted in [2] that AirCell's pole point formula included a minor error. AirCell claimed in [3] that Telcordia was incorrect, and provided a new definition and a mathematical derivation to support that claim. As shown here, the new definition is not useful and the derivation is incomplete and incorrect.

Summary of Response to [4]

AirCell has put forth a new proposal to support four separate systems in the ATG bands, using duplex inversion and polarization isolation. AirCell proposes two pairs of cross-duplexed sytems – one pair operating with vertical polarization and the other with horizontal polarization. Even ignoring the difficulties inherent in using polarization isolation in the air-to-ground environment, this new proposal depends on the duplex inversion scheme to control interference between co-polarized systems. As shown in [2], duplex inversion is not a reliable vehicle for spectrum sharing.

Moreover, AirCell's new analysis in [4], intended to support the new proposal, does not actually address a four-system scenario. It simply models two systems that are co-duplexed but cross-polarized, so any coupling effects between these systems and the other pair (which are cross-duplexed with respect to the first pair and cross polarized with each other) are completely ignored. AirCell does not address how a four-system sharing arrangement would actually be implemented (for example, base station placement and coordination for the four systems is not discussed).

In its simulation of cross-polarized systems, AirCell assumes a fixed polarization isolation of 12 dB, justifying this number by reference to a measurement report [5]. However, the purpose of the measurements described in that report was to assess the overall impact of AirCell's existing system on a cochannel terrestrial cellular system, not to determine polarization isolation. Detailed scrutiny of that report revealed no data or conclusions about polarization isolation. The basis of AirCell's assumed polarization isolation is therefore unclear.

Even taking AirCell's results at face value, those results show that with two cross-polarized systems sharing the ATG bands, the reverse link noise rise can be extremely large (up to 25 dB), whereas normal system design practice would limit it to around 6 dB for dynamic range and system stability reasons. Admission control and other mechanisms that would be used in a real system to enforce that limit seem to have been ignored in the AirCell simulations.

Detailed Response to [3]

Non-Idealities in the Link Budget
For the air to ground link, AirCell [1] assumed textbook free-space propagation with an additional loss of only 3 dB to account for cabling. Telcordia included "a system performance margin that accounts for non-idealities in propagation and implementation, including the effects of multipath and variations in antenna gain due to tolerance in the tilt and horizontal orientation" ([2], p. 15). The value used was 10 dB based on Airfone's operational experience.

In [3], pp. 10-11, AirCell advances several arguments against the inclusion of the margin in the link budget, concluding that "In summary, AirCell sees that adding any margin similar to Telcordia's M_{sys} value would produce a very misleading simulation of expected system performance."

Interestingly, in Appendix A of [4], AirCell reports on the results of aircraft to aircraft path loss measurements. These measurements were made for aircraft separations of about 6 km or less, and the aircraft elevation separation was about 1000 feet. Figure 1 and Figure 2 show the results from these measurements, reproduced from Figures A3 and A4, respectively, of [4]. The large variations are attributed to the aircraft antenna pattern and blockage from the aircraft body, which can have a significant effect at small separations due to the relatively large elevation angle difference between the two planes. While the Appendix does not provide the antenna pattern, it does state that the maximum gain is 4 dB. However, as can be seen, there is significant variation in the path loss, and rarely is it below the free space loss (indicated by the red line in Figure 1), even at the larger distances, for which the elevation angle between the two aircraft is small (for a 1000-foot vertical separation and a 5-km horizontal separation, the elevation angle is only about 3.5°), so elevation angle and blockage effects should not be significant.

As can be seen from Figure 1, at the larger distances, (4-6 km), the spread in path loss is about 0 to10 dB above free space. While AirCell has not reported on similar measurements for the ground-to-air path, it is reasonable to expect that there would be similar variation due to the same factors. In addition, the ground-to-air path is subject to additional degradation due to ground reflections, while the air-to-air path generally is not.

In sum, AirCell's claim that it is not appropriate to include the additional 10-dB margin in the link budget seems inconsistent with its own recently reported measurement data.
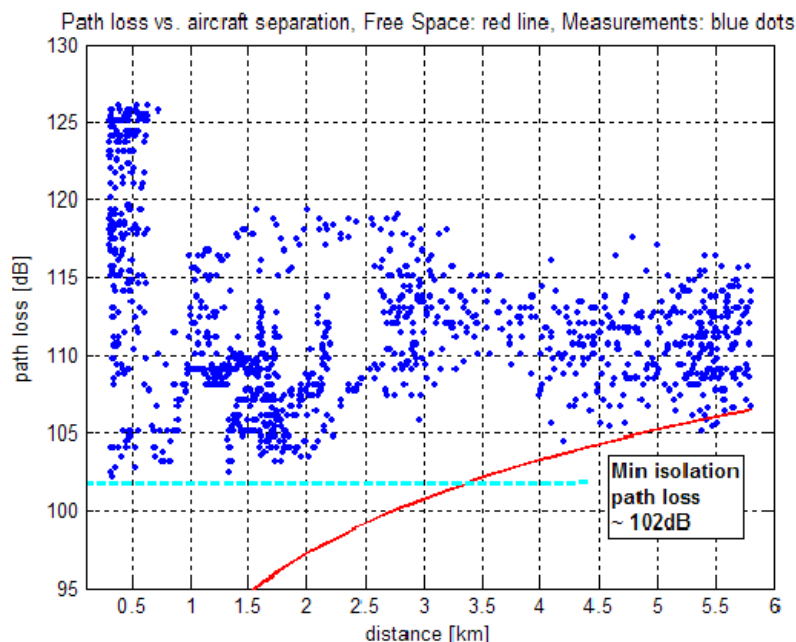

Figure 1: *Measurements of path loss isolation between aircraft, from Figure A3 of [4].*
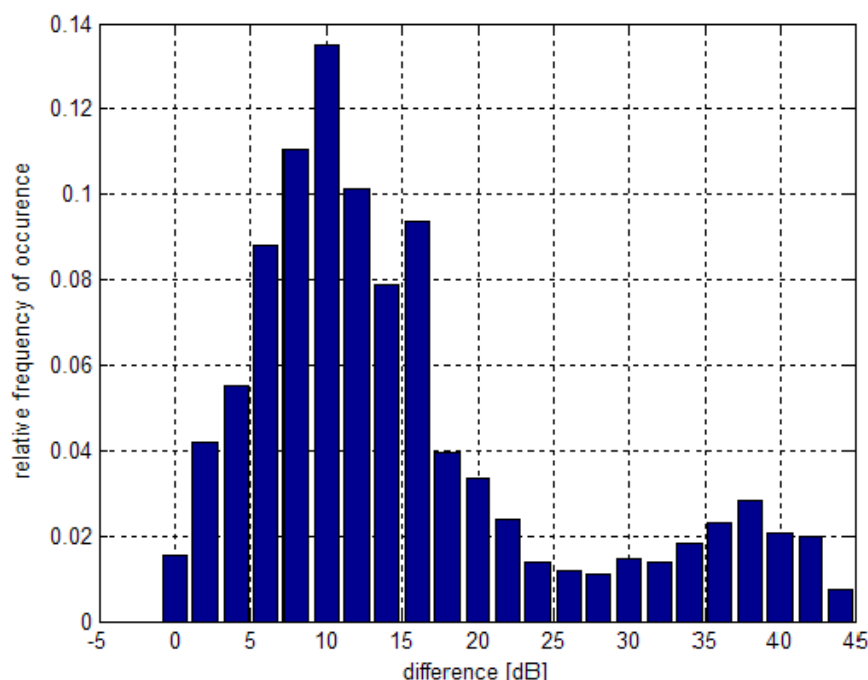
Figure 2: *Normalized histogram of additional isolation, from Figure A4 of [4].*

Base-to-Base Interference with Cross-Duplexed Systems

In [1], interference between base stations of cross duplexed systems was ignored, assuming that base station separation and antenna patterns would mitigate it ([1], p. 13). Telcordia pointed out that in AirCell's "airport scenario," cross-duplexed base stations are about 9.5 miles apart, whereas the radio horizon between base stations ranges from 17.9 to 43.8 miles, depending on the base station tower height, and further noted that base-to-base interference "will also be a concern in a real-world deployment situation as antennas will tend to be higher in built-up areas near major airports."

Telcordia provided no specific base-to-base interference calculations in [2], but simply pointed out that such interference cannot be ignored based on distance separation. Despite this, in [3] AirCell responded that "Telcordia's analysis was based on free space propagation, with no consideration for the terrain screening/obstruction loss, and with no consideration for the impact of the discrimination provided against the horizon with uptilted antennas."

In Appendix C of [4], AirCell provides calculations of base-to-base interference (using free space propagation, notwithstanding AirCell's comment in [3]), and relates the required "horizon null depth" ΔG to the separation distance between adjacent cross-duplexed base stations, for a received interference level that is 3 dB below the noise floor. The applicable geometry is shown in Figure 3, reproduced from [4], Figure C.3. The point "A" represents the minimum-altitude location of the aircraft which is communicating with the base station of System 1, and G_{max} is the maximum gain of the

base station antenna. The gain difference ΔG (dB) is the difference between G_{max} and the gain in the direction of the (victim) cross-duplexed base station, and θ is the elevation angle difference between the aircraft and the victim base station. Thus, the vertical antenna gain of each base station must change by ΔG dB over an angle of θ.
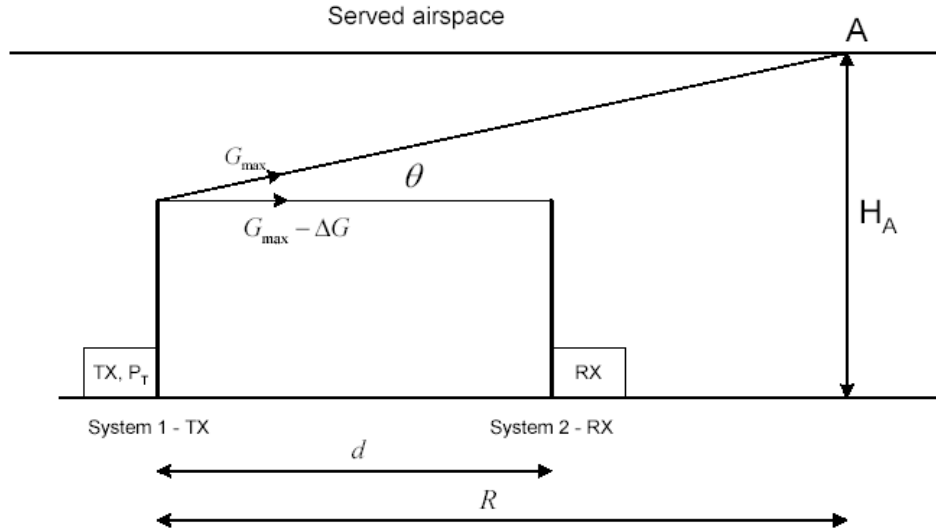

Figure 3: *Geometry for analysis of base-to-base interference for the airport scenario, reproduced from [4], Fig. C.3, page 89.*

Table C.2 of [4] shows ΔG for various base station separation distance. For example, for a 10-mile separation, ΔG is about 25 dB.

The problem with this analysis is that θ may be very small, making it unlikely that the required ΔG can be achieved. In AirCell's model, the minimum aircraft altitude for the airport scenario is 1000 feet and $R = 12.5$ miles (see [4], table 5.1, page 25). Neglecting the curvature of the earth (as did AirCell, [4], p. 88), this corresponds to an elevation angle of less than 1° above the horizon. This means that the antenna elevation gain must roll off by 25 dB within an elevation angle change of 1°. This does not seem to be realistically achievable from the perspectives of both antenna design and antenna alignment.

AirCell has thus failed to demonstrate that base-to-base interference can be reliably managed for cross-duplexed systems. It should also be noted that AirCell's analysis accounts for only a single interfering base station, whereas in reality each base station in the airport scenario will likely be affected by more than one cross-duplexed base station. With two interfering base stations, the interference would be equal to the noise floor, and even if the cross-duplex interference from the other base stations could be reduced to this level, there would still be a major degradation in the capacity of a CDMA reverse link, as shown below.

Impact of the AN/SPS-49 Naval Air Search Radar

In [2] (p. 53), Telcordia explained why interference from the AN/SPS-49 Air Search Radar used aboard Naval warships is likely to pose a greater interference threat to a cross-duplexed ATG system than to a system with normal duplex assignments. This conclusion essentially results from three factors:

1. Operation of the radar within 200 nm (230 statute miles) of land is limited to channels within the 902-928 MHz band.

2. An aircraft is much more likely to "see" the radar transmitter due to its greater radio horizon (about 250 miles for an aircraft vs. about 30 miles for a base station, depending on its elevation).

3. A receiver in the 894-896 MHz band will be more strongly affected by sidebands of a radar signal in the 902-928 MHz band than will a receiver in the 849-851 MHz band.

In [3], section 4, pp. 14-16, AirCell disputes this claim, but seems to misunderstand several key points.

First, AirCell claims that interference probability is low, because "ships turn off their AN/SPS-49 radar about 200 nm from the shore." This is not true; as noted above, and explicitly stated in [2], operation within 200 nm of shore is limited to the 902-928 MHz band. Moreover, as also explained in [2], Airfone has experienced problems from the AN/SPS-49 at its coastal base stations, which receive in the 894-896 MHz band. If the radars did not operate within 200 nm of shore, this would not be the case.

Second, in computing interference from radars to coastal base stations (to compare with the interference from radars to aircraft), AirCell seems to have neglected the effect of the radio horizon in its calculations, providing path loss calculations between a radar transmitter 25 nm (28.8 statute miles) off the coast and base stations that are "20 to 100 miles from the coast" [3], p 15. Due to the curvature of the earth, the radio horizon is limited to $d_{max} \cong \sqrt{2}\left(\sqrt{h_1} + \sqrt{h_2}\right)$, where d_{max} is in miles and h_1 and h_2 are the elevations in feet of the transmit and receive antennas. For a 150-feet ATG base station and a 100-foot radar transmit antenna (as an example), $d_{max} = 31.4$ miles. Thus, none of the base stations posited by AirCell will be affected by the radar transmissions, and AirCell's calculations are not valid.

Aircraft Transmit Power and Technology Evolution

The 23 dBm maximum aircraft transmit power assumed by AirCell in [1] was based on low-rate speech transmission on the reverse link, using CDMA technology, for which the relationships between the total received power, capacity, and the pole point are well known. However, Telcordia has shown that the interference impact of cross-duplexed spectrum sharing is very sensitive to the assumed reverse link transmit power. In the future, if more power is necessary to accommodate higher reverse link data rates (possibly using a technology other than CDMA), to support services other than a small

number of low-rate speech circuits (which are provided already with Airfone's existing technology), then AirCell's assumed parameters no longer apply. Clearly, adopting FCC Rules that allow cross-duplexed operation would constrain the aircraft transmit power to low levels in order to control the cross-duplex interference, effectively limiting the potential for future technology growth. AirCell's response on this topic is simply: "We expect that the majority of the reverse link traffic will be voice (using one or more Voice over IP standards) with asymmetric high bit rate data transactions (consistent with web browsing-type applications) dominating on the forward link." ([3], p. 8). There are no references or reasons given for this somewhat myopic view of future wireless technologies. Recent history has shown that wireless technologies and the applications that they enable continue to evolve, and it would be a mistake to assume otherwise in establishing new rules to support broadband services in the ATG spectrum.

Reverse Link Pole Point Formula
In Annex B of [2], Telcordia develops the CDMA reverse link load relationship

$$\frac{I_{tot}}{N} = \frac{1}{1 - K/K_{pole}} \tag{1}$$

where I_{tot} is the total noise plus interference at the base station receiver, N is the thermal noise floor, K is the number of active mobiles per cell or sector, and K_{pole} is the "pole capacity", which is the asymptotic capacity limit as $I_{tot}/N \to \infty$. Telcordia noted in Annex B of [2] that the pole point analysis provided by AirCell in [1] had a minor error, which resulted in the expression

$$\frac{I_{tot} + Pf}{N} = \frac{1}{1 - K/K_{pole}} \tag{2}$$

where P is the power received from each in cell mobile and f is the other-cell interference factor. That is, if the power received from all in-cell mobiles is $I_{in} = KP$, then the power received from all out-of-cell mobiles is $I_{oc} = fI_{in} = fKP$, and the total noise plus interference is then $I_{tot} = KP(1 + f) + N$. The parameter f depends on cell geometry, distribution of mobiles, and propagation, but not on K.

AirCell, in its reverse link pole point analysis in [1] (pp. 22-23), used the parameter I_{adj}, which it defined as "the ratio of out of cell to in-cell interference" but did not provide a mathematical definition. In its assessment of the AirCell model summarized above, Telcordia equated I_{adj} to the parameter f, leading to the expression for I_{tot}/N given above.

AirCell, in its subsequent response [3] to the Telcordia paper [2], stated that Telcordia's interpretation was incorrect because $I_{adj} \neq f$, and defined I_{adj} as

$$I_{adj} = \frac{I_{oc}}{\sum\limits_{j \neq i} P_j}, \qquad (3)$$

whereas $f = I_{oc} \Big/ \sum\limits_{j} P_j$. AirCell asserts that with this definition for I_{adj}, "the analysis of the pole point provided by Telcordia is accurate and essentially identical to AirCell's analysis." ([3], p. 7). AirCell [3] attempts to demonstrate this by comparing several of the Telcordia equations with "equivalent" AirCell expressions based on the definition of I_{adj} in (3). However, as shown below, when the final steps of the analysis (omitted by AirCell in [3]) are taken, it is clear that the AirCell formulation is not equivalent to the Telcordia formulation. The reason is that unlike *f*, which is a constant, I_{adj} as defined in [3] is not a constant, because it depends on the reverse link load. For *K* identical mobiles, $I_{adj} = I_{oc} \big/ (K-1)P$, whereas $f = I_{oc} \big/ KP$. Thus, $I_{adj} = f \cdot K \big/ (K-1)$, and I_{adj} depends on the number of mobiles per cell. However, in [3], AirCell treats it as a constant, and the result is that if AirCell's equations 3.8 and 3.10 in [3] are combined to give a load relationship, the result is incorrect.

AirCell equation 3.8 is

$$(M+1)P = N + (K-1)(1 + I_{adj})P + P \qquad (4)$$

which can be rearranged to give the active number of mobiles per cell (*K*) as a function of received power per in-cell mobile (*P*) as

$$K = 1 + \frac{M}{1 + I_{adj}} - \frac{N}{P(1 + I_{adj})} \qquad (5)$$

AirCell equation 3.10 gives the pole capacity as

$$K_{pole} = 1 + \frac{M}{1 + I_{adj}} \qquad (6)$$

Combining (5) and (6) gives

$$K = K_{pole} - \frac{N}{P(1 + I_{adj})} \qquad (7)$$

Rearranging and substituting for K_{pole} gives

$$\frac{P}{N}\left(1 + M + I_{adj}\right) = \frac{1}{1 - K/K_{pole}} \qquad (8)$$

With $I_{tot} = (M + 1)P$ this becomes

$$\frac{I_{tot} + PI_{adj}}{N} = \frac{1}{1 - K/K_{pole}} \qquad (9)$$

which clearly is not equivalent to the Telcordia load curve expression in (1). The reason is the hidden dependence of I_{adj} on K. In (5), $I_{adj} = fK/(K-1)$, whereas in (6), $I_{adj} = fK_{pole}/(K_{pole} - 1)$. Thus, the definition of I_{adj} provided in [3] is not useful.

Detailed Response to [4]

In [1], AirCell proposed to use duplex inversion to share the ATG bands between two independent service providers. In [4], AirCell proposes sharing of the bands among four providers using both duplex inversion and polarization isolation. One pair of cross-duplexed systems would share each polarization (horizontal and vertical). In the analysis provided in [4], AirCell assumes an invariant 12 dB of isolation is provided by the orthogonal polarizations. AirCell also proposes the use of switched-beam antennas at the base stations but acknowledges that "The benefits on both links are inversely proportional to the loading at all systems. For highly loaded systems, due to a large number of aircraft, most beam segments will be active." ([4], p. 29). Thus, when interference mitigation is needed most (in heavy loading), it is least effective: "If all beams are active, there is no isolation gain from switched beam antennas." ([4], p. 32).

The analysis in [4] focuses on interference between a pair of ATG systems that are co-duplexed but cross-polarized. For the cross-duplexed systems, [4] relies on the results previously provided in [1], which have already been addressed in [2]. Unfortunately, [4] does not actually analyze or simulate a 4-system sharing scenario but rather simulates only a 2-system scenario, where the two systems are co-duplexed but cross-polarized. Any interaction or coupling among the two pairs of systems is ignored:

Since cross-duplex operation has been shown to provide sufficient isolation, System 1 can safely coexist with systems 3 and 4. Demonstrating that systems 1 and 3 can coexist would thus in effect complete the argument that four CDMA systems in spectrum allocation plans proposed in Section 4 are feasible. Therefore, analyzing inter-system interference between systems 1 and 3 (or equivalently between 2 and 4) is the main contribution of this report ([4], p. 28).

This reasoning is flawed on several accounts. To explain them clearly it is helpful to use the following table as a reference for the duplexing and polarization relationships (see Figures 4.1, 4.3, and 4.5 of [4]):

	duplexing	
pol	*normal*	*reversed*
V	System 2	System 1
H	System 4	System 3

Here "normal" duplexing is ground-to-air at 849-851 MHz and air-to-ground at 894-896 MHz, consistent with the current ATG rules.

It appears that the passage quoted above was intended to state that on the basis of the earlier analysis of [1], "system 1 can safely coexist with systems 2 and 4" rather than "3 and 4". With that correction, the logic of the passage might be paraphrased as: "It has been shown that two co-polarized, cross-duplexed systems (e.g., 1 and 2) can coexist. Therefore, if it can be shown that two co-duplexed but cross-polarized systems (e.g., 1 and 3) can coexist, then all four systems (1, 2, 3, and 4) can coexist." However, this fails as a logical proposition because pairwise analysis ignores coupling between the pairs. For example, it was shown in [4] that with the co-duplexed but cross-polarized sharing, a substantial noise rise can be induced in the base station. Even assuming that the excessive noise could be tolerated, it would increase the required aircraft transmit power, which would increase interference to the cross-duplexed but co-polarized aircraft, and therefore would affect the analysis of coexistence between the cross-duplexed pairs.

Figure 4 (reproduced from [1], p. 57, Figure 34) shows a histogram of the aircraft transmit power from [1], for the airport scenario with loading at 75% of the pole point. The disproportionately large probability associated with 23 dBm is due to the fact that in the simulation, AirCell constrained the aircraft transmit power to a 23 dBm maximum. Although the probability associated with 23 dBm is off the scale, the other levels sum to about 0.8, suggesting that the probability that the transmit power was 23 dBm is about 20%. This is for the cross-duplex case, in which interference among cross-duplexed base stations was ignored.

Figure 5 shows the cumulative distribution function (CDF) of the noise rise from [4] (p. 54, Figure 6.23) for two cross-polarized but co-duplexed systems. Note that it can become quite large, considering that good design practice dictates that it generally should be about 6 dB or less. This large noise rise causes the aircraft transmit power to be

correspondingly high, as shown in the associated CDF for the aircraft transmit power in Figure 6, reproduced from [4], p. 54, Figure 6.22. It appears that for 75% loading, the transmit power is greater than or equal to 23 dBm more than 40% of the time. The CDFs of the noise rise suggest that were it not for the 23 dBm limit, the aircraft transmit power would be considerably greater than 23 dBm in some cases with high loading.   This would in turn increase the aircraft-to-aircraft interference for the cross-duplexed systems.
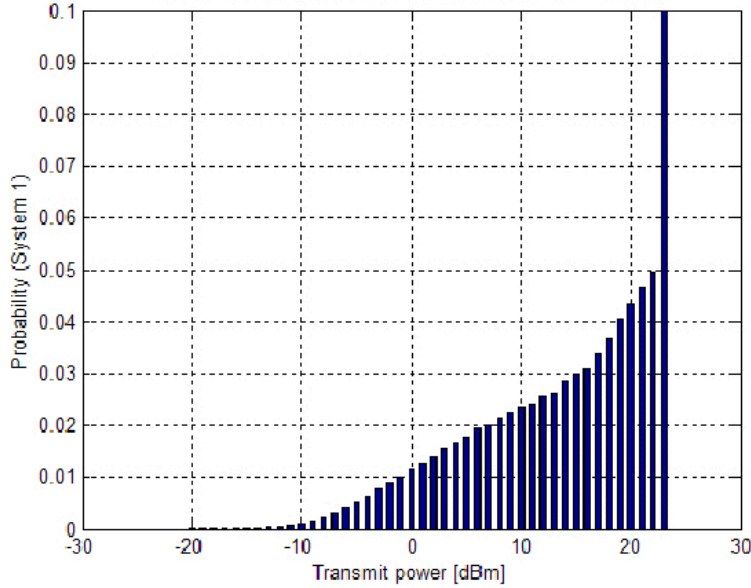

Figure 4: *Histogram of aircraft transmit power from [1], page 57, airport configuration, 75% of pole point loading and 40% spectrum overlap.*
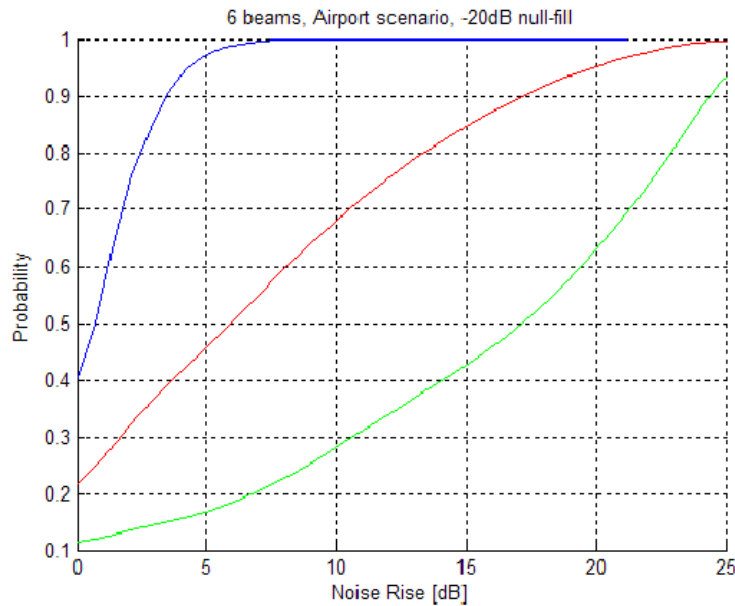

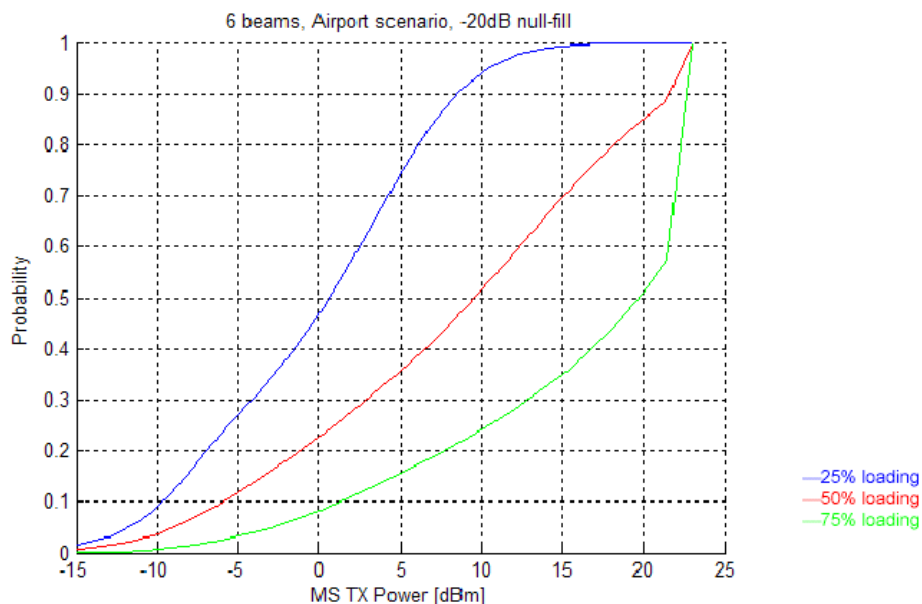**Figure 5:** *Example CDF of the noise rise from [4], p. 54.*

Figure 6: *CDF of aircraft transmit power from [4], p. 54.*

It is clear from this example that the potential for coexistence of four systems under AirCell's most recent proposal cannot adequately be evaluated by pairwise analysis (one pair of cross-duplexed, co-polarized systems and a separately-analyzed pair of co-duplexed, cross-polarized systems), because that approach ignores coupling effects. The interactions of all four systems must be considered jointly.

Another significant issue which is not addressed by the pairwise analyses that AirCell has provided is base station placement. In both [1] and [4], the same base station placement pattern is used for the simulation. That placement is shown in Figure 7 (reproduced from [2], p. 9, Figure 3). In [1], the two systems are co-polarized but cross-duplexed, whereas in [4] they are co-duplexed but cross-polarized. AirCell has not explained how it proposes to arrange base stations under the four-system proposal. Moreover, as explained in [2] (pp. 10-12), even for two systems, the geometry used by AirCell in its simulations cannot be replicated to uniformly tile a plane.

Even disregarding the effect on aircraft transmit power and the resulting increased aircraft-to-aircraft interference to cross-duplexed systems, the large noise rise reported by AirCell in its analysis of the cross-polarized systems is a problem. As noted, the noise rise on the CDMA reverse link is typically held to a modest value (e.g., around 6 dB) to limit the required dynamic range of the front-end low noise amplifier, and to prevent system instability. AirCell itself acknowledges this, stating: "from the plots of the reverse link transmit power it is evident that by the time a system reaches the 75% loading, it is already causing an excessive amount of self-interference. For that reason, it is very unlikely that an operator would allow the system to be loaded to the 75% of pole capacity" ([1], p. 47).
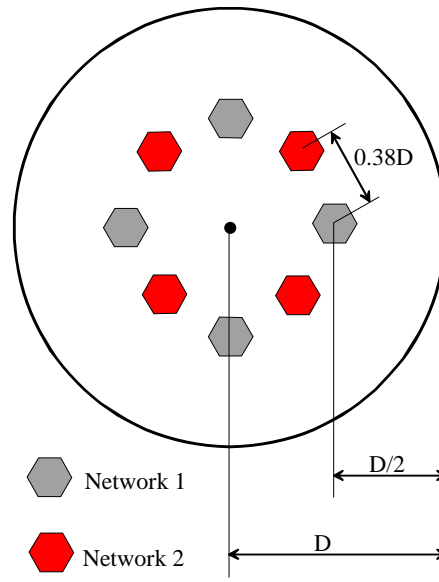
Figure 7: *The AirCell simulation model geometry (from [2], p. 9).*

In practice, admission control mechanisms would be used to enforce the noise rise limits. A simulation that does not account for this is inherently unrealistic. AirCell acknowledges the noise rise problem, stating that "interference management techniques" or "cell splitting" could be used to mitigate it ([4], pp. 49-50). The only "interference management" technique discussed seems to be "0 dB null-fill", which AirCell acknowledges "is not very realistic" ([4], p. 57), and even with this approach, "The noise rise values in the 75% loading case are quite large" ([4], p. 58). One problem with cell-splitting is that it places base stations closer together, which reduces flexibility in base station siting and aggravates the base-to-base interference problem with cross-duplexed operation.

Finally, AirCell's polarization-isolation analysis in [4] suffers from the same flaws as the duplex-inversion analysis of [1]: unrealistically idealized link budget assumptions, a very limited service model, which supports an average of 48 kb/s per aircraft on the reverse link, and a hard limit of 23 dBm on the aircraft EIRP. In addition, there appears to be no rational justification for the key parameter used, the polarization isolation. AirCell states on p. 13 of [4]:

> In practice, the level of polarization isolation is hard to predict analytically. Measurements are necessary to determine the exact polarization isolation between antennas. Such measurements have shown that isolations on the order of 15 dB are realistic in ATG links [reference to [5]]. In this report, a conservative value for polarization isolation of 12 dB is used to investigate the impact of two additional CDMA systems added using orthogonal polarization. The addition will result in two pairs of cross-spectrum systems, each pair operating at one of the linear orthogonal polarizations, horizontal or vertical.

In fact, examination of [5] reveals no basis whatsoever for assuming 12 dB polarization isolation, or any other value. The purpose of the measurements described in that report was to assess the overall impact of AirCell's existing system on a cochannel terrestrial cellular system, not to determine polarization isolation: "This test was structured to quantify interference that the AirCell system is likely to produce" ([5], p. 5). The report does not provide any data about polarization isolation, nor are any conclusions about polarization isolation values given in the text, summary, or conclusions.

Measurement of polarization isolation would require transmission with one polarization (i.e., horizontal transmitted polarization from the aircraft) and collocated vertically- and horizontally-polarized receive antennas with identical gains and patterns, with time-synchronized received signal sampling from both. The post-processing would compute the dB difference between the two, and then construct the CDF of the polarization isolation from the data set. There is no indication in the report that any such measurements or comparisons were made. It therefore remains unclear how AirCell concluded that 12 dB was a reasonable value for the polarization isolation in the ATG environment. In any case, the polarization isolation would not be a fixed value but would vary, and would need to be modeled as a random variable.

Summary Comments on AirCell Proposals and Analyses

Sharing Using Duplex Inversion

Base-to-Base Interference

In the airport environment, it often will not be possible to separate base stations by distances exceeding the radio horizon, and AirCell's model geometry reflects this – cross-duplexed base stations are about 9.5 miles apart, whereas the radio horizon will range from about 18 to 44 miles, depending on the base station antenna elevations. AirCell initially ignored this problem, but as summarized above, AirCell has now [4] proposed to mitigate it by careful use of antenna patterns. As explained above, AirCell's proposed solution does not appear to be workable due to the extremely demanding angular resolution required. However, even if this solution could be implemented, it would introduce an interference power 3 dB below the noise floor per interfering base station.

If there are two cross-duplexed base stations visible, then the interference is equal to the noise floor. The impact on the capacity of a CDMA reverse link is easily seen rearranging (1) to be $K/K_{pole} = 1 - N/I_{tot}$, so that if the upper limit on I_{tot} is held constant, then the ratio of the capacity with the added interference (denoted K_2) to the original capacity is

$$\frac{K_2}{K} = \frac{1 - N_2/I_{tot}}{1 - N/I_{tot}} \tag{10}$$

For a 6-dB maximum allowed noise rise (a reasonable value), $N/I_{tot} = 0.25$, so if the added "noise" from the cross-duplexed base stations is equal to the noise floor, then $N_2 = 2N$ and $K_2/K = 0.67$. Thus, the added interference from the cross-duplexed base stations has cost the reverse link one-third of its capacity. One conceivable solution would be to de-sense the base station receiver by adding some attenuation to the receive path, to render the cross-duplexed base station interference less significant relative to the noise floor. However, this would require an increase in the aircraft transmit power, which would worsen the aircraft-to-aircraft cross-duplex interference.

Overall, AirCell's proposed antenna-null solution to the base-to-base interference problem is not practical, and even if it were, the interference would still significantly degrade the CDMA reverse link capacity.

Service Model and Aircraft Transmit Power
Even ignoring the base-to-base interference problem, AirCell's optimistic results supporting sharing by duplex inversion depend heavily on one thing: a very low total power transmitted from each aircraft. To keep the aircraft transmit power sufficiently low in its simulations in order to minimize interference effects, AirCell relies on three key assumptions:

1. The service paradigm is limited to a small number (~10) of low-rate speech channels for a total average throughput of 48 kb/s per aircraft on the reverse link, whereas the forward link provides high-rate data via 1xEV-DO.

2. The link budget is assumed to be textbook-perfect free space propagation, aside from a 3-dB allowance for cable loss. No margins are allowed for fading, equipment implementation loss, antenna tolerances and misalignment, etc., all of which can and do occur in actual installations.

3. The aircraft EIRP is hard-limited to 200 mW, equal to the RF output power limit of a single digital cellular handset.

As shown in [2], when the aircraft EIRP is increased, the interference effects become considerable, resulting in severe degradation to the forward link. Significantly, AirCell has not denied this, but has instead continued to insist that both its limited service paradigm and its idealized link budget assumptions are realistic. Thus, adopting duplex inversion as a regulatory vehicle to support spectrum sharing in the ATG bands is tantamount to imposing severe data rate limits on the reverse link, and ignoring the degradations and service outages that will frequently occur due to non-ideal operating conditions.

To see the relationship between data rate and required power, Figure 8 can be used together with the relationship

$$\frac{E_b}{N_t} = \frac{W}{R} \cdot SINR \tag{11}$$

where E_b is the received energy per bit, N_t is the power spectral density of the noise plus interference, W is the RF bandwidth, R is the data rate, and $SINR$ is the signal to interference plus noise ratio. Figure 9 shows the modulation efficiency R/W vs. the SINR, which clearly shows that for a fixed bandwidth, as the data rate increases, the SINR (and hence the transmitted power) must increase.
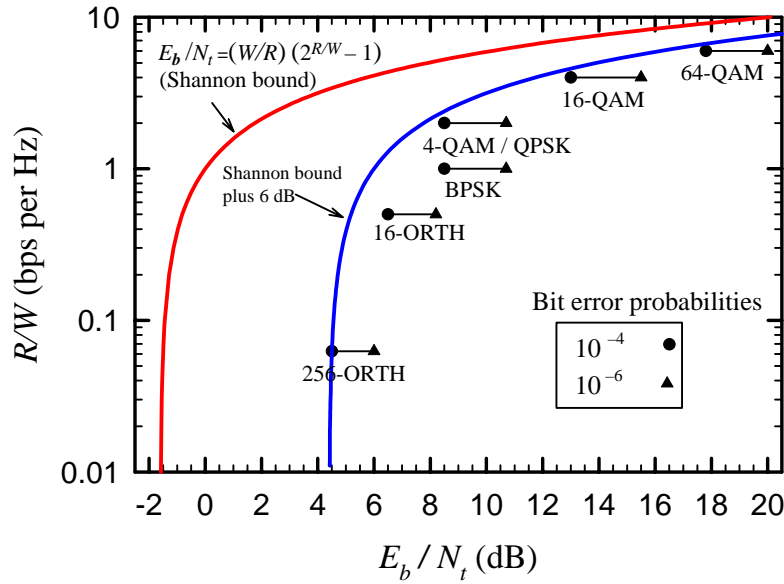

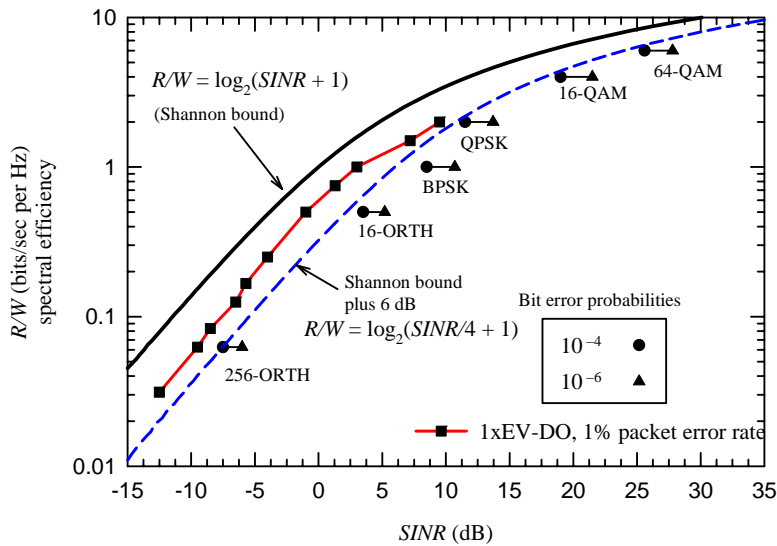**Figure 8:** *Modulation efficiency vs. E_b/N_t.*

Figure 9: *Modulation efficiency vs. SINR.*

The relationship between SINR and modulation efficiency can be approximated as $SINR \cong \alpha\left(2^{R/W} - 1\right)$, where $10\log\alpha$ is the offset from the Shannon bound in dB. This means that the ratio of the SINR requirements associated with two different rates R_1 and R_2, transmitted over the same bandwidth W, can be written as:

$$\frac{SINR_2}{SINR_1} = \frac{2^{R_2/W} - 1}{2^{R_1/W} - 1}. \tag{12}$$

Figure 10 shows this SINR ratio in dB as a function of R_2, for $R_1 = 48\,\text{kb/s}$ and $W = 1.25\,\text{MHz}$ and Figure 11 shows the same relationship but with the relative SINR as an absolute ratio rather than in dB, which makes it clear that the required SINR increases faster than linearly as the data rate increases.

The conclusion is clear: broadband services and their associated higher transmission rates will require higher transmit power levels than the low-rate speech services assumed by AirCell.
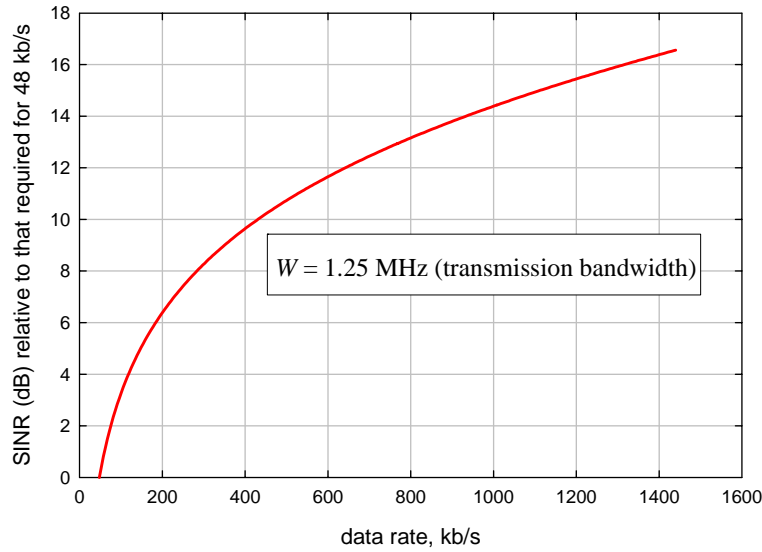

Figure 10: *SINR in dB above that required for a 48 kb/s rate on a 1.25 MHz channel.*
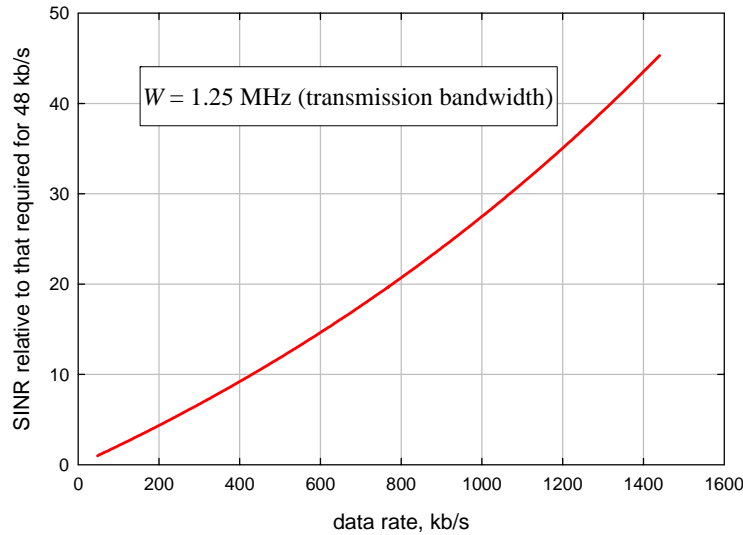
Figure 11: *Same as Figure 10 but with the relative SINR as an absolute ratio.*

Interference from Naval Air Search Radars

As explained in [2], an aircraft receiving in the high ATG band (894-896 MHz) will be much more likely to suffer interference from the AN/SPS-49 air search radar used by the U. S. Navy, due to the much greater radio horizon of the aircraft. AirCell has attempted to refute this fact, but as noted above, neglected to account for radio horizon limits on interference to base stations in its calculations, so its conclusions are not valid.

<div align="center">*****</div>

In summary, AirCell has not explained how duplex inversion can be used in a practical implementation, including management of base-to-base interference, aircraft-to-aircraft interference, and mitigation of interference to duplex-inverted aircraft from the AN/SPS-49 radars. Further, AirCell has failed to show how the duplex-inversion concept can be made to offer the flexibility needed to accommodate the growth and evolution of broadband wireless technologies that will inevitably occur, and will result in higher reverse-link power requirements as data rates increase. Adoption of duplex inversion as a regulatory solution would severely limit the service growth potential of the ATG bands. AirCell's contention that a 48 kb/s throughput is all that will be needed on the reverse link is not credible.

Four-System Sharing Using Polarization Isolation and Duplex Inversion

AirCell has recently enhanced its proposal by suggesting that four systems can share the ATG spectrum using both duplex inversion and polarization isolation. In [4], AirCell provides simulation results of a single pair of systems that are co-duplexed but cross-polarized. AirCell has not reported on any actual analysis or simulation of all four systems operating together, nor has it explained certain operational details pertaining to four-system operation, such as base station placement. Further, AirCell has made the

assumption that if one pair of cross-duplexed, co-polarized systems can be shown to coexist, and one pair of co-duplexed, cross-polarized systems can be shown to coexist, then it follows that all four systems can successfully coexist. As explained above, this is not a valid assumption. Moreover, as has been shown in [2], even the single pair of cross-duplexed systems cannot successfully coexist outside of the very limited parameter space that AirCell has used in its simulations described in [1].

In its analysis of a single pair of co-duplexed, cross-polarized systems presented in [4], AirCell assumes a fixed 12 dB isolation between the vertically and horizontally polarized systems, which is justified by reference to a report which does not provide any relevant data [5], so the credibility of AirCell's claim that the required polarization isolation can be maintained between the two systems in the scenarios simulated by AirCell in [4] is questionable. However, even taking AirCell's results from [4] at face value, it is clear that it is not feasible for two co-duplexed systems to share spectrum using polarization isolation due to the extreme noise rise (on the order of 25 dB in some cases) induced at the base stations. In actual CDMA systems, this reverse link noise rise is tightly controlled (by admission control mechanisms and power control) to limit it to some nominal value (e.g., 6 dB) to ensure stability and adhere to constraints on the dynamic range of the base station front-end low noise amplifier (LNA). AirCell's simulations failed to account for such real-world factors.

In addition, AirCell's analysis of the cross-polarized systems in [4] also suffers from the same deficiencies as its analysis of cross-duplexed systems in [1], including a very limited and unbalanced service paradigm, idealized implementation assumptions, and a hard limit of 200 mW on aircraft EIRP. Also, there was no analysis of interactions between vertically polarized incumbent ATG systems and new cochannel horizontally-polarized systems (see, e.g., [4] Figure 4.7, p. 23). In fact, as noted, "Full analysis of the interference between narrowband and CDMA system 3 requires better understanding of traffic loading of the two systems . . . more thorough analysis that takes the actual traffic into account should be performed" ([4], p. 23).

Conclusion

AirCell has proposed sharing of the 849-851 and 894-896 MHz ATG bands among four systems using duplex inversion and polarization isolation but has not reported on any analysis or simulation of simultaneous operation of all four systems. One pair of cross-duplex systems and one pair of cross-polarized systems have been analyzed separately, and as explained here and in [2], even for these pairwise cases, coexistence is not practical. Given that, coexistence of four systems in the ATG bands clearly will not be viable.

References

[1]   Ivica Kostanic and Dan McKenna, "Evaluation of the ATG Spectrum Migration Concept," March 10, 2004, AirCell report to the FCC, WT Docket 03-103.

[2]   Anthony A. Triolo and Jay E. Padgett, "Coexistence Analysis for Multiple Air-to-Ground Systems," June 3, 2004, Verizon Airfone report to the FCC, WT Docket 03-103.

[3]   V. Tarokh and A. Varadachari, "Response to Telcordia Technologies Comments on AirCell Proposal," June 17, 2004, AirCell report to the FCC, WT Docket 03-103.

[4]   Ivica Kostanic, "Evolution of the ATG Migration Concept (Part 2)," June 29, 2004, AirCell report to the FCC WT Docket 03-103.

[5]   C. J. Hall and I. Kostanic, *Final Report of AirCell Flight Tests,* TEC Cellular, July 10-11, 1997.

Response to Recent Boeing Filing

Anthony A. Triolo, Ph.D.
17 August 2004

This response addresses issues raised in a recent filing by Boeing in WT Docket 03-103. A summary of Telcordia's responses is presented first and a detailed discussion of the issues follows thereafter.

Summary of Response to [3]

1. Boeing states that Telcordia ignored the Boeing submission of April 29th [1], since Telcordia asserted that adaptive antennas would be necessary to support multiple co-duplexed (overlapping in frequency) providers. Telcordia was, in fact aware of the Boeing submission. However, it was not fully clear from that submission that the Boeing concept for spectrum sharing rests entirely on the fact that all providers *must* place base stations on a regular grid. It did not seem that the grid-based system was a workable solution and Telcordia assumed that the grid was used for simplification of modeling, not as the entire proposed solution. To that end, a grid-based system's many shortcomings were not addressed in Telcordia's previous filing, but will be addressed here. A summary of these shortcomings is:
   a. An unfair advantage would exist for those providers on the grid that are located near major airports, due to better signal coverage to larger numbers of aircraft.
   b. Each provider would likely need more than one base station in these high traffic areas to provide capacity. This is not possible when each provider is restricted to one base station per grid point.
   c. Increasing grid density to improve capacity penalizes the provider with the smallest market share. To maintain reasonable signal to interference ratios, every provider must install more equipment when the inter-base-station distance shrinks (higher grid density).
   d. The near-far problem still exists, even for a grid based layout.
   e. Aircraft monitoring applications would be eliminated, since providers with base stations far from airports could not monitor landing aircraft due to the radio horizon.
2. When co-duplexed base stations are placed in a more reasonable manner, i.e., competing providers will place base stations near high aircraft density regions (near airports), the situations presented in the previous Telcordia submission [2] will be very likely to happen, i.e., several competing base stations clustered around major airports. In this case, co-channel interference cannot be mitigated with reasonably sized antennas.
3. Boeing presents what is labeled a "worst-case" near far condition and shows that there is not an interference problem in this case due to an aircraft antenna null in the downward direction. We will show in the following that the case presented by Boeing is not really a worst-case, and will present a situation based on a slightly

modified version of the Boeing assumptions where a near-far interference condition does exist.

4. Boeing draws parallels between their proposed switched beam system and Airfone's proposed switched beam system to imply that the two proposed systems are not very different. What they fail to clearly point out is that the Boeing proposal additionally requires *all providers* to place their base stations on a centrally managed grid.

5. Results from the simulations presented in the April 29th submission [1] are used to bolster the claim that multiple providers can coexist without interference problems if all providers place their base stations on the uniform grid. It is shown that these simulations apparently fail to take into account the high data rates expected for a broadband air-to-ground service. If more reasonable data rates are assumed, increased interference will be experienced by all providers.

Detailed Response

In the Boeing response dated 14 July 2004 [3], Boeing takes issue with the fact that Telcordia assumes all providers would require adaptive antenna systems in order to make the system of spectrum sharing proposed by Boeing feasible. Boeing's initial proposal relied on the fact that all competing providers would be distributed on a uniform grid throughout the entire United States. This layout seemed impractical from many points of view and was not used in the Telcordia analysis. Instead, a more reasonable assumption was made that multiple providers would all like to be located where the highest density of aircraft exists, i.e., close to airports. With this clustered geographical distribution of base stations and a co-duplexed spectrum sharing arrangement, the same issues as presented in the previous Airfone/Telcordia submission [2] would hold. For example, clustered base stations would be seen as very close together in angle as seen from a distant aircraft and an impractically large antenna array would need to be employed to provide enough antenna discrimination for each system to operate effectively.

Some of the reasons that the uniform grid-geographical distribution seemed unreasonable include:

1. Since the density of aircraft near the airports is high, there would exist an unfair advantage for those providers on the grid that are located near major airports, i.e., these close-in providers would have better signal coverage to larger numbers of aircraft.

2. Even more importantly, each provider would likely need more than one base station near each airport to provide the required capacity.

3. Boeing states that capacity can be increased by cutting the inter base-station distance and increasing the density of base stations (always keeping everyone on a uniform grid, though). This system of capacity increase is inherently unfair to the smallest provider. When the largest provider (in terms of market share) increases its grid density, the smallest provider will experience much more interference from the extra base stations and will be forced to also increase its grid density even though its network carries less traffic.

4. There is a potential near-far problem associated with this grid-based system.

5. Since base stations located far from airports would not be able to communicate with approaching aircraft below certain altitudes (due to the radio horizon), this would eliminate the possibility of aircraft monitoring links over the broadband

connection. At the least, this would provide an additional unfair service advantage to providers with base stations near the airports.

6. It is difficult to maintain the uniform grid along the irregular coastlines; an area where a large majority of air traffic resides.

Item #1 is supported by the fact that Verizon Airfone's legacy base stations are not uniformly distributed, as shown in Figure 1 and Figure 2. Upon close inspection of these figures, one can observe that base stations are clustered around major airports. In the Northeast/Mid Atlantic area (Figure 1) or the Chicago area (Figure 2) there are multiple base stations within fairly small areas. This clustering is typical around the major airports. There are base stations that are less than 1 mile apart, some that are 4 miles apart, and even more that are 15 – 20 miles apart. This is in contrast to Boeing's proposed separations in the approximate range of 80—100 miles. The reason for this kind of clustering is that the highest density of air traffic is located around these airports and the required network capacity can only be provided by multiple base stations. It is similar to the practice of cell splitting that is performed by terrestrial cellular providers in order to increase network capacity. Also, good signal coverage at these locations is important in maintaining a viable service and can only be achieved by proximity or higher transmitted power (up to the radio horizon). Therefore, it is reasonable to believe that most other ATG service providers would like to be close to these high density locations. In addition, if a uniform grid were imposed on the ATG spectrum, Verizon Airfone would be forced to remove and relocate a significant number of base stations.

Figure 1: Map showing Airfone current base stations in the Northeast/Mid Atlantic region. Note the non-uniform spacing and clustering near airports. The two closest base stations are less than 1 mile apart.

Figure 2: Map showing current Airfone base stations near Chicago. Note the two base stations near the airport. These base stations are 4 miles apart.

If it were not required that a uniform base station grid be imposed on the ATG spectrum, the situation presented in the previous Telcordia submission [2] would be very likely to occur. It is in this clustered interfering base station environment that adaptive antennas would need to be employed in order to reject interference. Additionally, as presented in [2], there are certain situations where reasonably sized adaptive antennas would not provide enough interference rejection.

Boeing points out in their latest submission [3] that their system is workable using a switched beam antenna, much the same as the one proposed by Airfone. Their Table 1 [3] seems to imply that the only difference between Airfone's proposed solution and Boeing's is that Boeing's solution allows spectral sharing through channel staggering and Airfone's does not. What the Table does not mention is that Boeing's proposal imposes one very important additional requirement, that is that all providers must constrain (or constrain closely) their base stations to a centrally managed uniform grid. A modified and corrected version of this table is shown below in Table 1.

Table 1: Corrected version of Table 1 from [3].

	Spatial Diversity, Directional Aircraft Antenna	Spectral Diversity, Channel Staggering	Polarization Diversity, V and H	Cross Duplex Operation	Segmented Base Station Antennas	Uniform Grid of Base Stations
AirCell		x	x	x	x	?
Airfone	x				x	
Boeing	x	x			x	x

In response to the near-far problem: In [3], Boeing presents what they call a "worst case" scenario. This scenario is most definitely not the worst case when employing Boeing's proposed antenna, even when using a regular grid of competing base stations. The case presented by Boeing as "worst" shows an aircraft that is directly over the interfering base station and where the desired base station is on the horizon. In this situation, the aircraft is as close as it can get to the interfering base station, but the aircraft antenna pattern puts the interfering base station in a null at -90° elevation (straight down from the aircraft). A situation worse than the case Boeing presents occurs when the aircraft is not in the null, but slightly out of the null. For example, using Boeing's proposed 85 mile spacing between competing BTSs and an aircraft flying at 30,000 feet, with the aircraft at 8 miles from the interfering base station and 77 miles from the desired base station, the free-space path loss to the desired BTS is 133.5 dB, and the path loss to the interfering base station is 115 dB. The elevation angle to the desired BTS in this situation is -4.45° and to the interferer is -36.9°, resulting in an angular difference of 32.45°. This gives a pattern rejection of less than 3 dB according to Figure 3 of the Boeing document [3], as compared to the 30 dB cited at 90°. Therefore, in this case, the signal from the interferer is 18.5 dB greater than the signal from the desired base station, but the pattern rejection provided by the aircraft antenna is only 3 dB. If we assume that the base station antenna has a similar null shape in the upward direction, we may achieve 3 dB of additional isolation. This still results in a signal-to-interference ratio of -12.5 dB, which results in an outage for a 1xEVDO system. The point here is that the 60 dB of pattern isolation that Boeing uses to demonstrate the ability of their antennas to alleviate near-far interference is only achievable directly above (>60 dB is achievable in a 1.6 mile radius about the base station as shown in Figure 3) the interfering BTS and cases do exist where near-far interference can be a major problem.
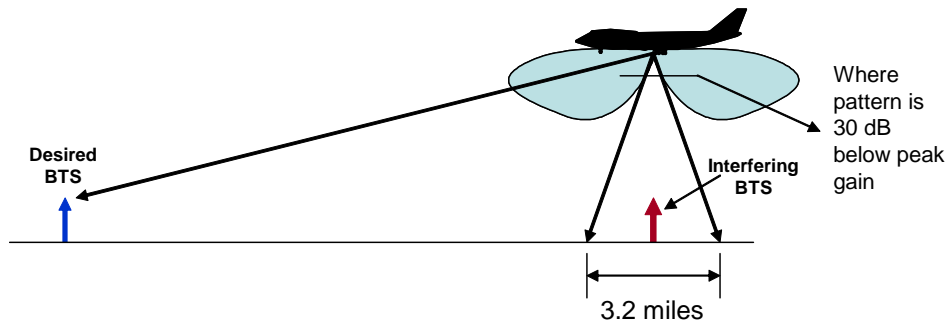

Figure 3: Example showing possible near-far interference problem. The aircraft is flying at 30,000 feet.

Simulation results were presented in [1] and referenced in [3] that show that cross-country simulations demonstrate no interference problems when multiple providers are present on a uniform grid. There are several questionable assumptions and factors that these simulations did not take into account. It is unclear exactly what aggregate data rate was assumed by Boeing, but it seems that a data rate of only 180 kbps ground-to-air (on-board) and 45 kbps air-to-ground (off-board) per large aircraft is assumed, i.e., 12 kbps per user ground-to-air and 3 kbps per user air-to-ground. These rates are very low and are not very different from the current Airfone service offering. Rates such as these do not account for growth and changing demand for such a service and are not even close to the rates that are being planned by Airfone for broadband service. Airfone is currently

planning for ground-to-air aggregate demand of >2.5 Mbps and air-to-ground aggregate demand of 960 kbps. This is more akin to current terrestrial broadband mobile data services. Because Boeing assumes very low data rates, a large amount of coding and spreading can be used to accommodate low signal to noise ratios and they can argue that many systems can possibly share the same spectrum. However, the resulting data rates in such a situation would be unacceptably low. Using much higher and more reasonable data rates that passengers are demanding, the proposed system would likely not be viable due to reduced coding gain and the increased transmit power necessary for higher speed operation (increased Ec/Io requirements for high rates). Secondly, while Boeing argues that these simulations show that a large number of links would not be affected to the point that they "do not close", Boeing's simulation fails to address the reduction in throughput that would be seen by all or some providers in such a spectrum sharing scenario.

In conclusion, the grid-based system of spectrum sharing proposed by Boeing would be difficult to maintain and manage. Since airports have a high density of air traffic in close proximity, it is reasonable to expect that competing providers would each like to be located near major airports. If a grid system is imposed, this would result in unfair placement for some providers, would eliminate the possibility of aircraft monitoring applications for some, and would require centralized coordination of base station placement. If the grid-based system was not imposed and multiple providers located base stations near airports, the situation presented in [2] would occur and an unreasonably sized antenna would be needed to discriminate between interfering and desired base stations.

Boeing's previous simulations of a nationwide grid-based system do not take into account real broadband operation. Even using the originally proposed low data rate estimates, these simulations show that there is not a large number of links that "do not close", but does not address the data throughput reduction that would be experienced with interference present. When using more reasonable data rates, the outage rates predicted in the original simulation [1] would be expected to be much higher.

References
[1] Boeing's Proposed ATG Sharing Rules with Supporting Analyses, Filed with the FCC on April 29, 2004.

[2] Coexistence Analysis for Multiple Air-to-Ground Systems, Filed with the FCC by Telcordia Technologies on behalf of Verizon Airfone on June 3, 2004.

[3] Boeing ATG Update Report. Filed with the FCC on July 14, 2004.